Scalable Pre- and Post-Processing Approaches for Large-Scale Computational Electromagnetic Simulations

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Parallel Finite Difference Time Domain Solver:

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Global Objective

Develop a scalable computational environment to solve large-scale practical Army applications

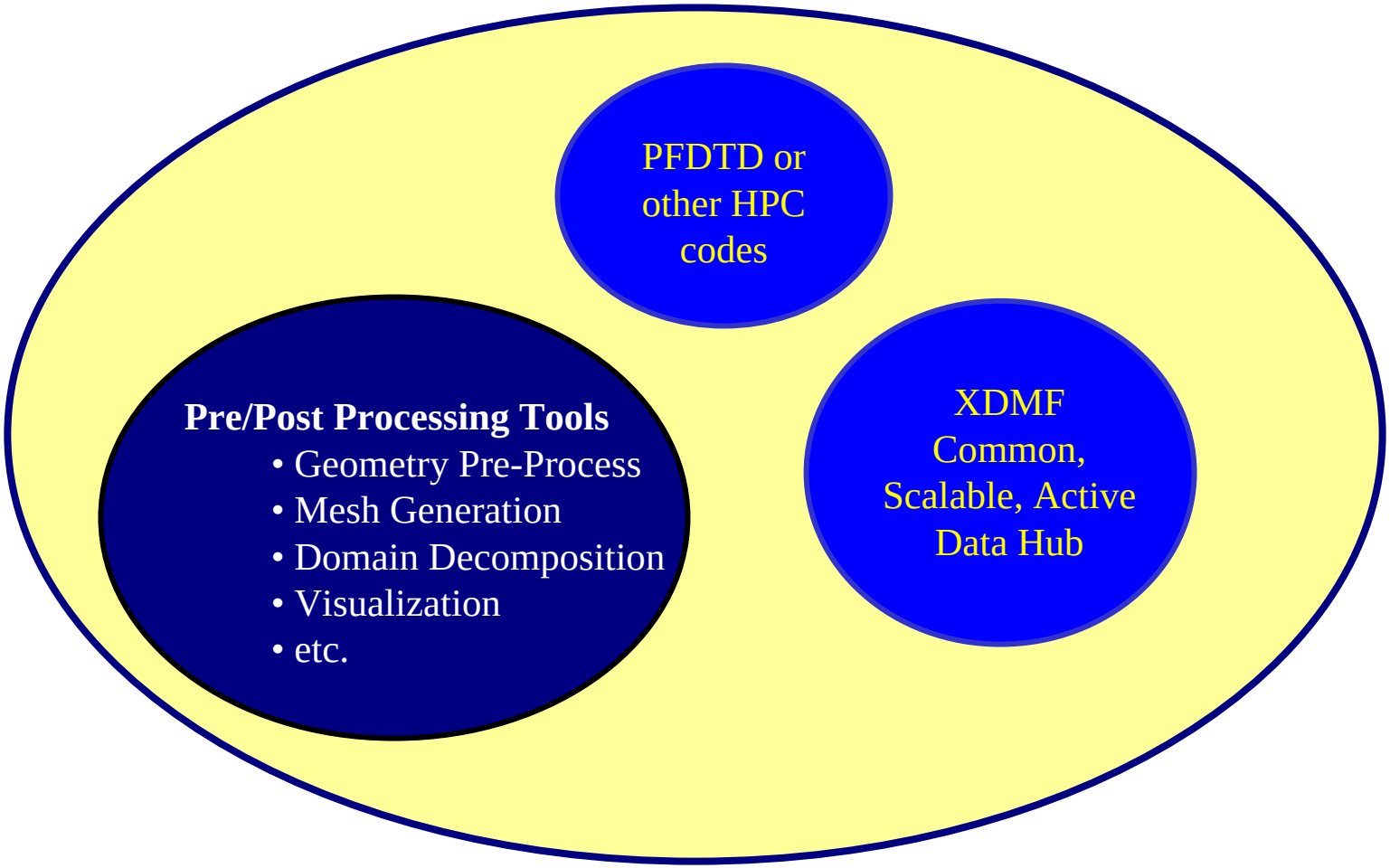
- **Scalable pre-processing software for generating meshes of the order 10e9 cells**
- **Parallel domain decomposition methods for obtaining scalability for the solver**
- **Scalable software: finite difference time domain method**
- **Post-processing approaches for visualizing parallel output generated from the above simulations (> 1Tbyte)**

Project Goals

- **Pre-processing tools starting from CAD or facet geometry**
- **Domain decomposition**
- **Integrate scalable solver into ICE**
- **Post-process large scale volumetric results including run-time visualization**

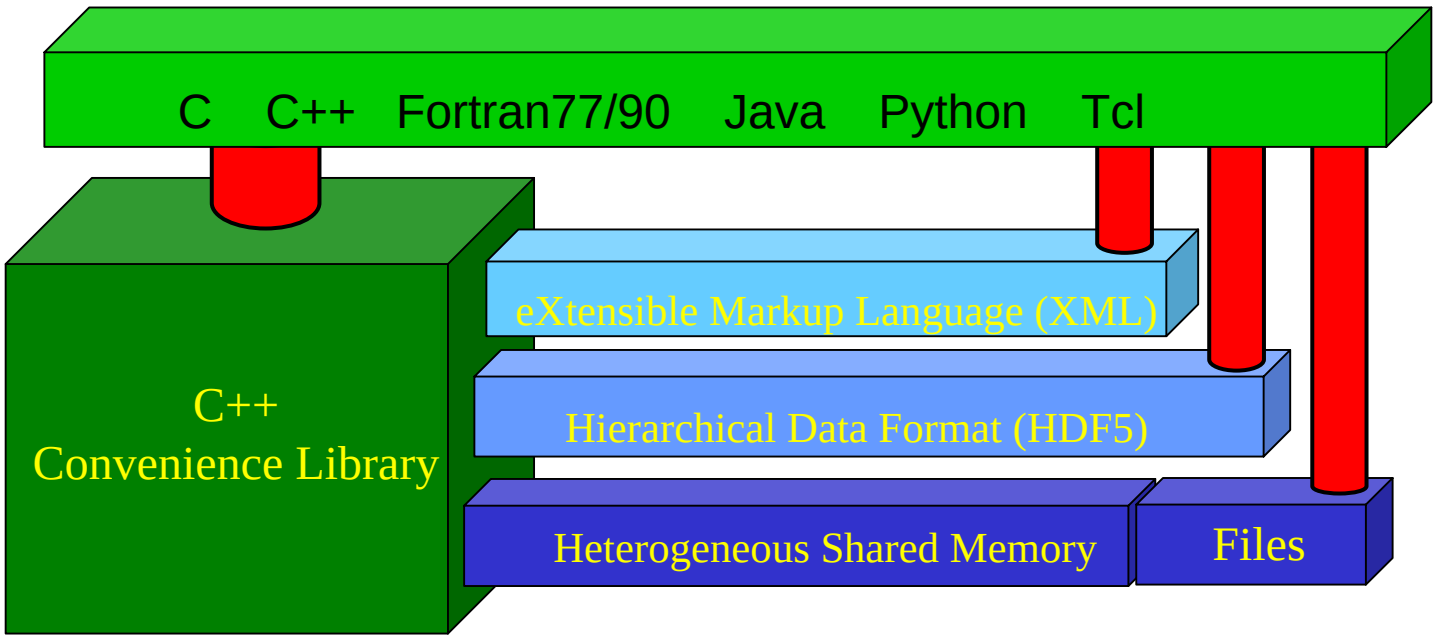
Demonstrate ability to simulate the response of a full-scale ground vehicle at X-band using a first principles solver.

Interdisciplinary Computing Environment (For CEM)



XDMF eXtensible Data Model and Format

- **Developed at ARL**
- **Unique Distributed Cooperative Memory System**
- **Uses HDF5 (*NCSA*) and XML**
- **Performance Friendly**
- **Language Neutral**



Solution Process

Mesh Preparation

- facet or CAD file
- check normal orientation
- add thickness to geometry
- wrap model with implicit mesh

Domain Decomposition

- subdivide implicit mesh

Mesh Generation

- distribute implicit mesh to multiple PEs
- generate mesh blocks in parallel

Solver (integrated into ICE)

- distribute mesh and absorber blocks to PEs

Visualization

- XDMF for data format, model & access
- visualize using ICE tools (Python/VTK based)

Scalable Mesh Generation

Surface Scan of Existing Objects

CAD Models

Facets/Polygons

Wedges/Thickness

Define Implicit Structured Mesh

Domain Decomposition

Parallel Generation of the Mesh

(number of PEs for mesh generation does NOT have equal the number of PEs for solver)

Input Generation

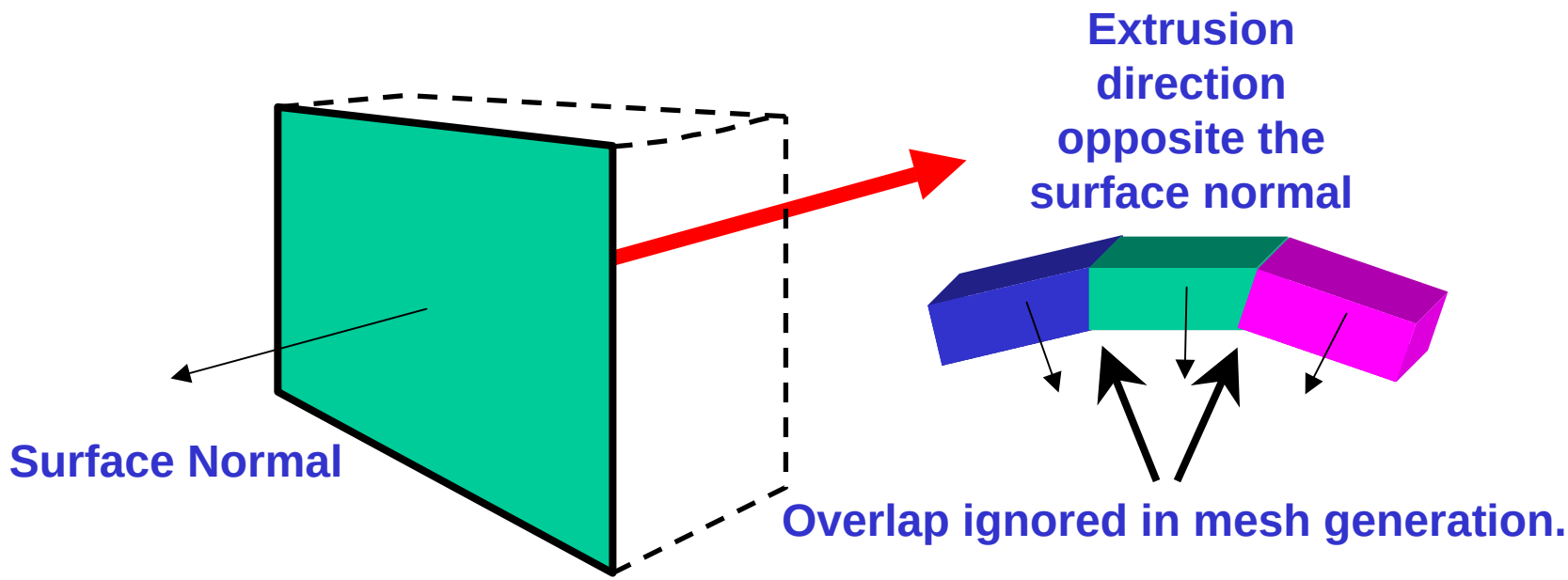
Rebuilding complex geometry in appropriate input format can be extremely time consuming.

Generate grid from existing model.

- **Read data into ICE (XDMF)**
- **Pass through a geometry filter to check facet normals.**
- **Generate wedge of a specified thickness from each facet.**

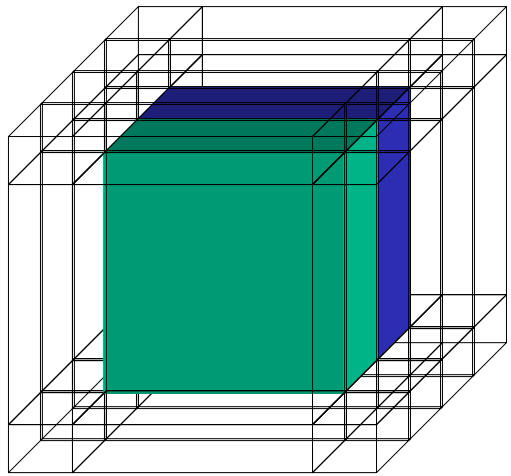
Geometry Conversion

Each facet in model is selected and extruded. Extrusion depth is frequency dependent. Typically set to 3x to 5x final mesh cell dimensions.



Domain Decomposition

- Implicit modeler envelops geometry
- Partitioning based on the PFDTD input file (user specified)
- Individual blocks are divided among user specified number of PEs for meshing.



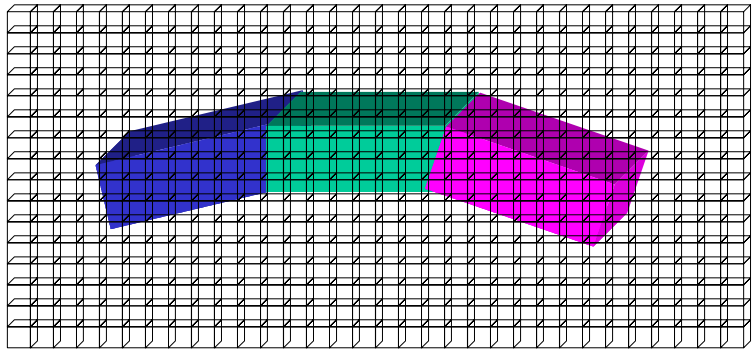
2 computational blocks

34 implicit absorber blocks

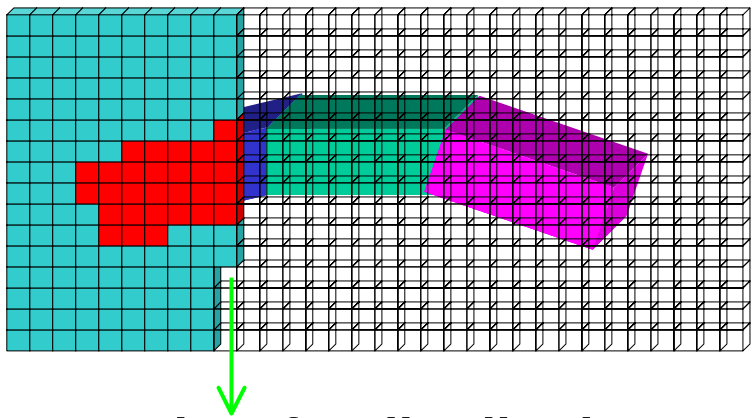
4 x 3 x 3 decomposition

Mesh Generation

Implicit modeler envelops geometry



then marches through generating a rectilinear structured mesh with a single material per cell.



Individual 3D meshes for distribution to multiple PE's

Scalable Visualization

Volumetric Output per CPU written to local file system.

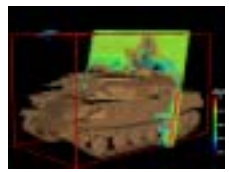
NDGM

Data blocks reassembled into Shared Memory Buffer

Using XDMF

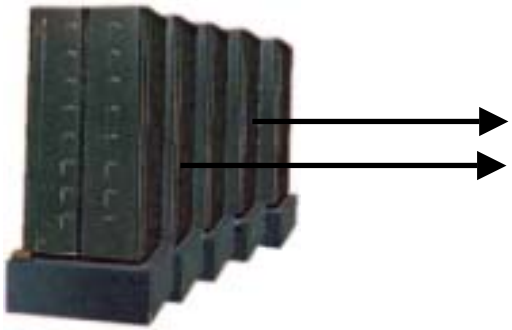
(eXtensible Data Model and Format)

Parallel Isosurface Generation using ICE tools.



Output to display or image file.

Scalable Run-Time Visualization



NDGM

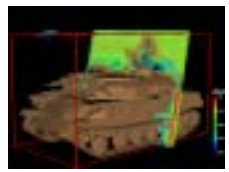
Full Time Step in Memory

Using XDMF

(eXtensible Data Model and Format)

Volumetric Output written to NDGM buffer as solver progresses.

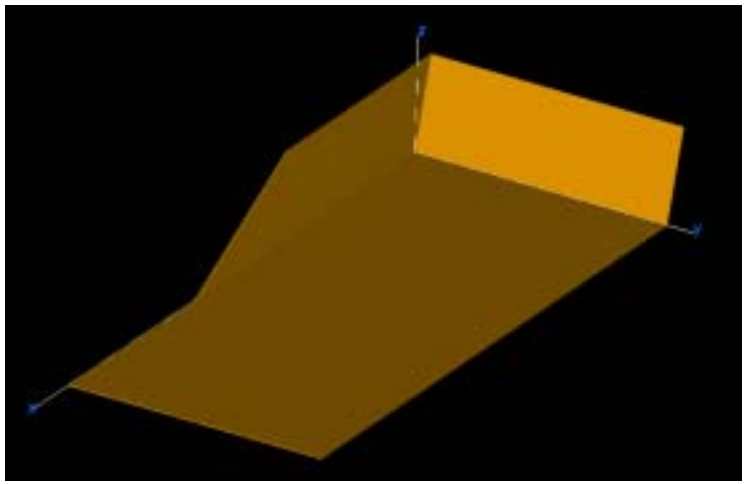
Parallel Isosurface Generation using ICE tools.



Output to display or image file.

Scalability Study of PFDTD under ICE

T5M3 Trihedron



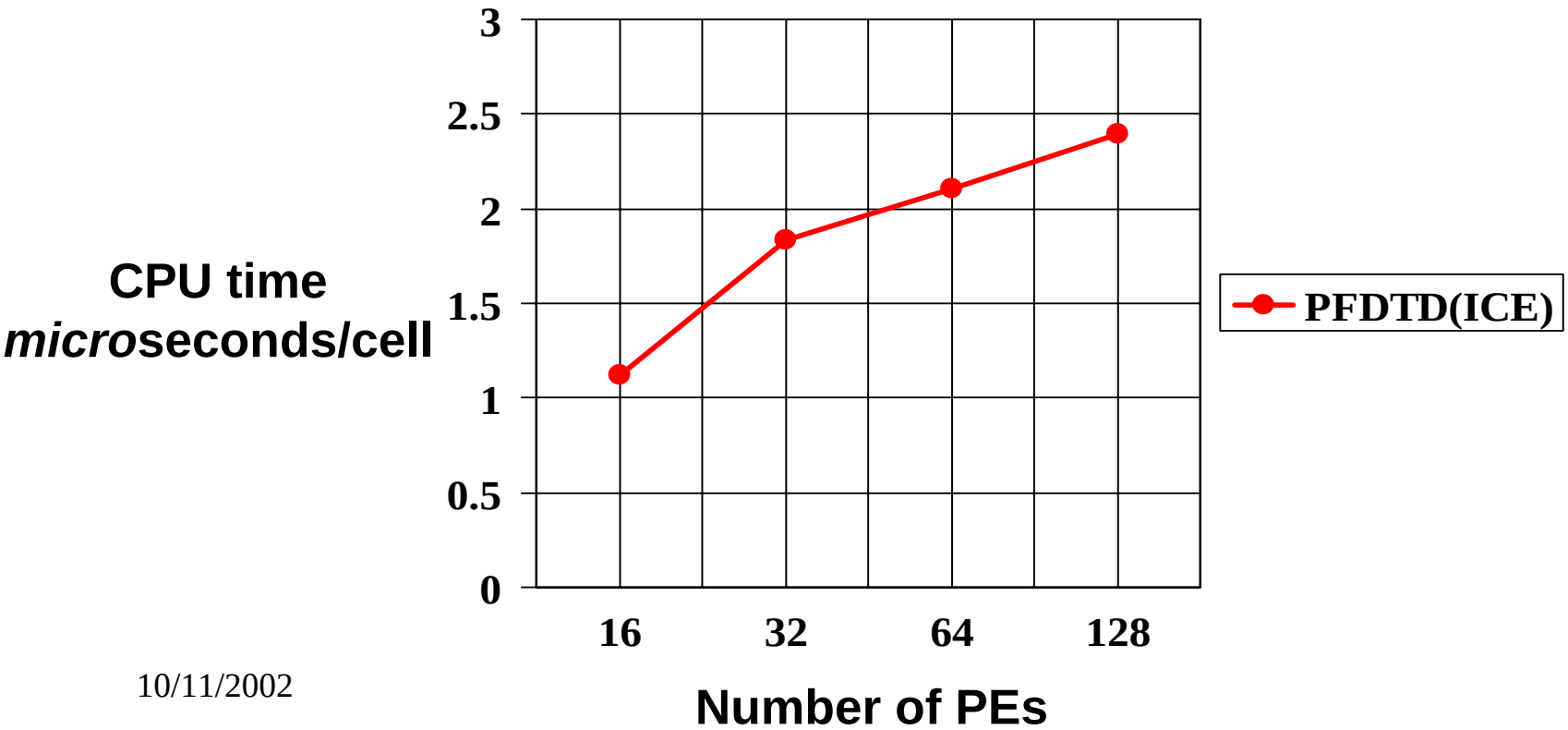
Part of T5M3 Ground Vehicle Simulator developed by the National Ground Intelligence Center

Optics based solvers have difficulty generating accurate results at certain elevation/azimuth angles.

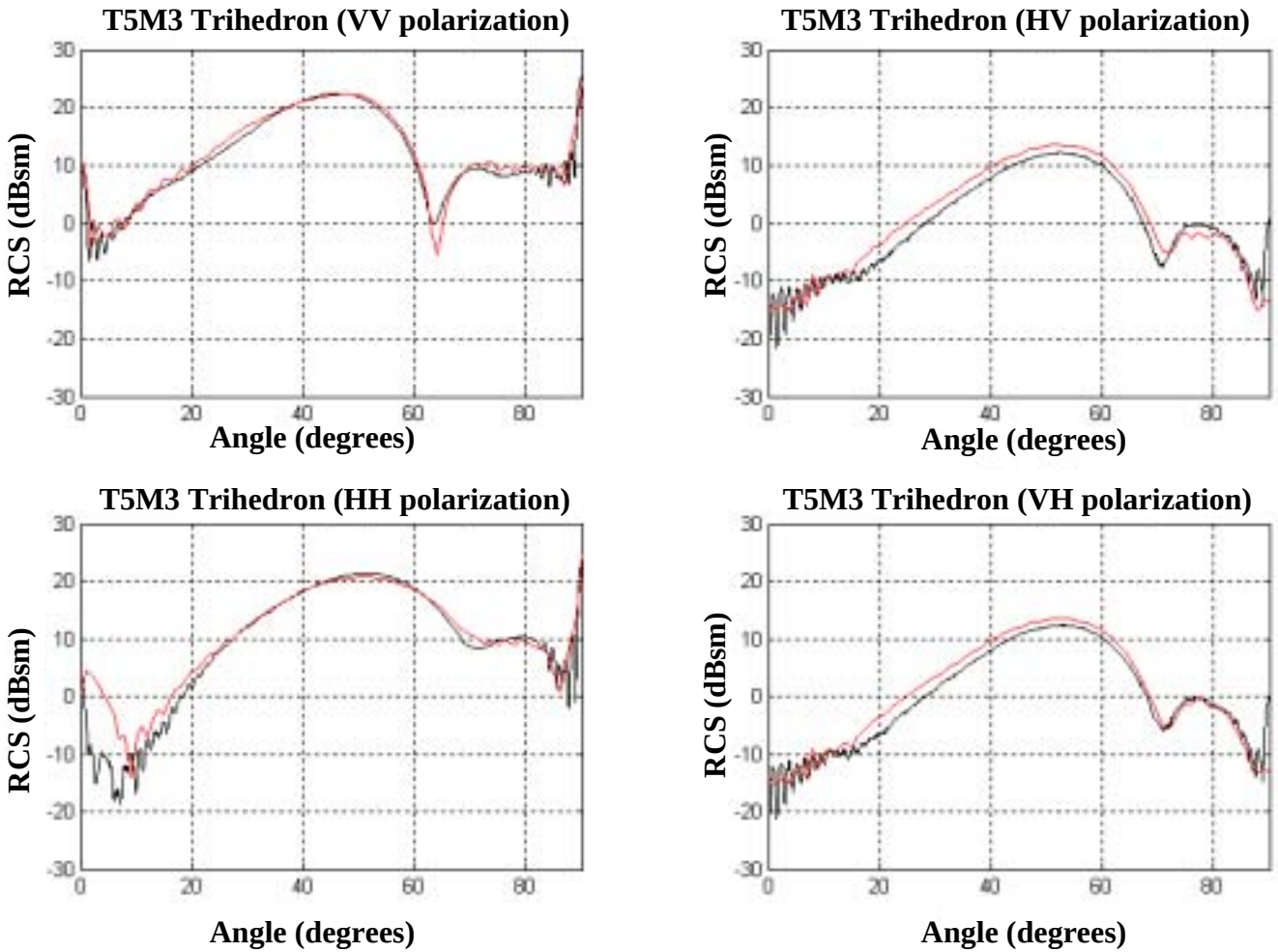
Scalability Study of PFDTD under ICE

T5M3 - Trihedron

89 million cell mesh - (1037 x 468 x 184) for 6000 TS



RCS results of PFDTD under ICE



Large-Scale Application

ZSU23-4 Anti-Aircraft Vehicle

2.5 billion cell mesh

384 PEs - ARL IBM-SP3

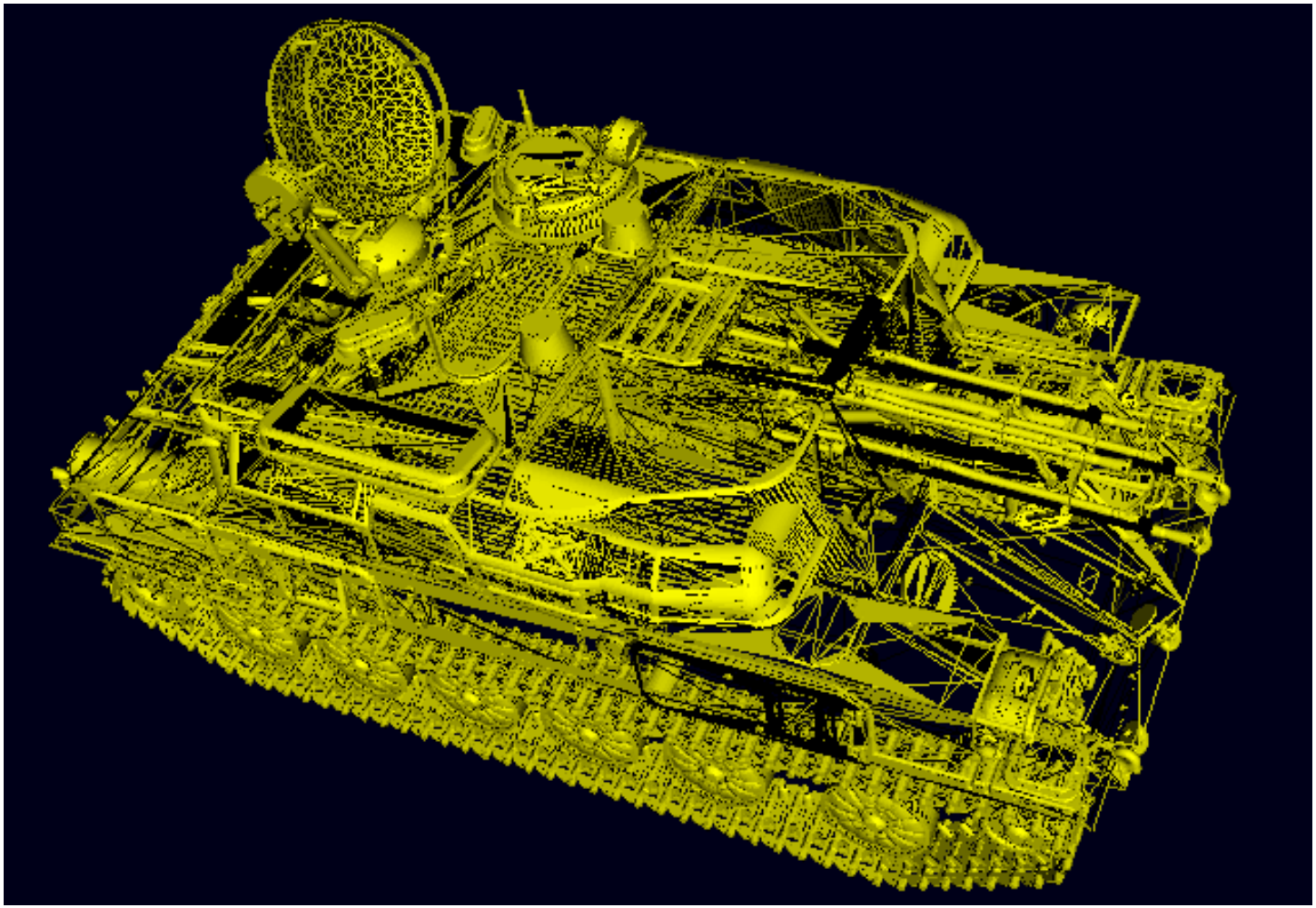
290GB memory

32.6 wall clock hours

(1984 x 1043 x 1188 cells) - 17000 timesteps

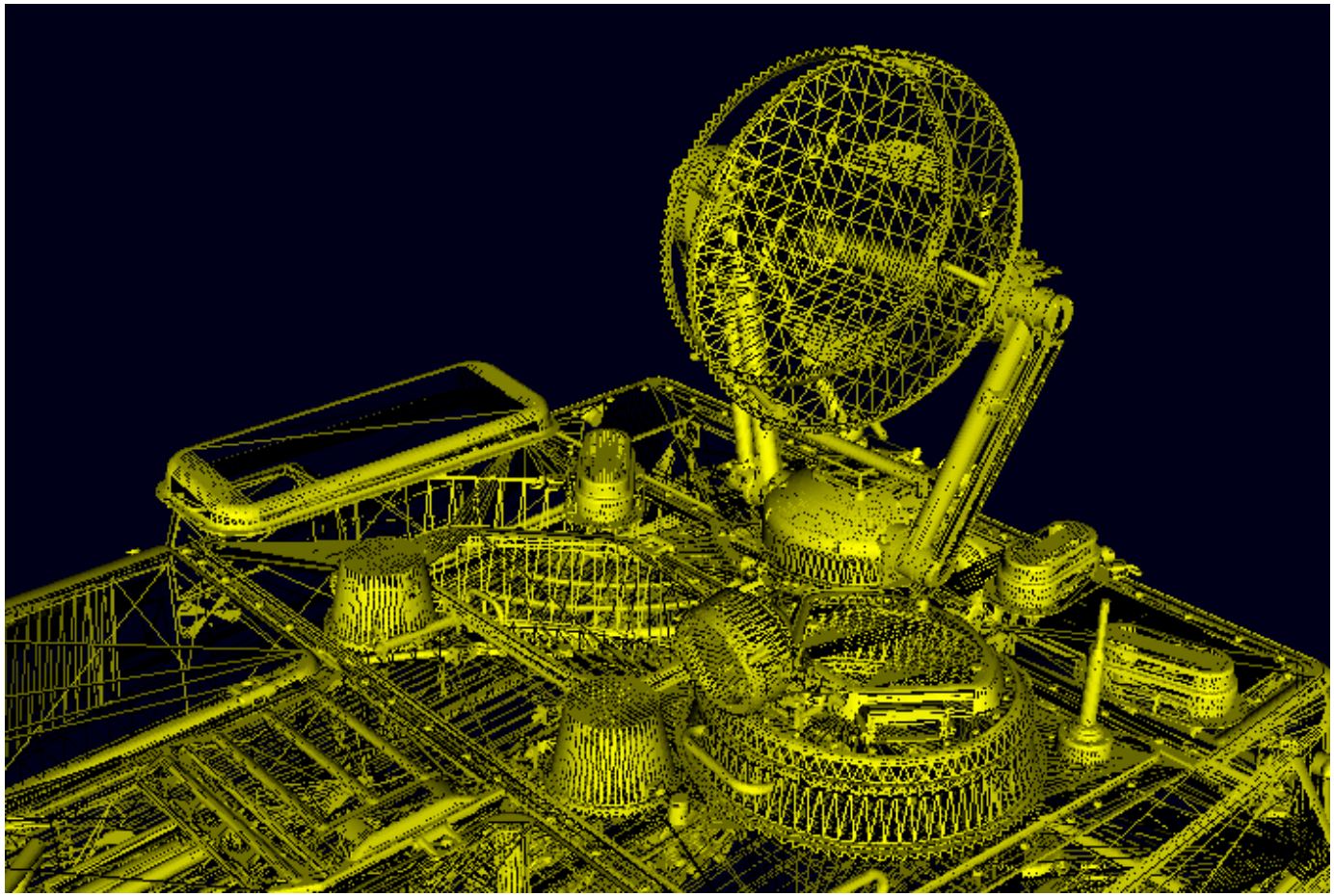
For one incident/azimuthal angle

Original Surface Mesh



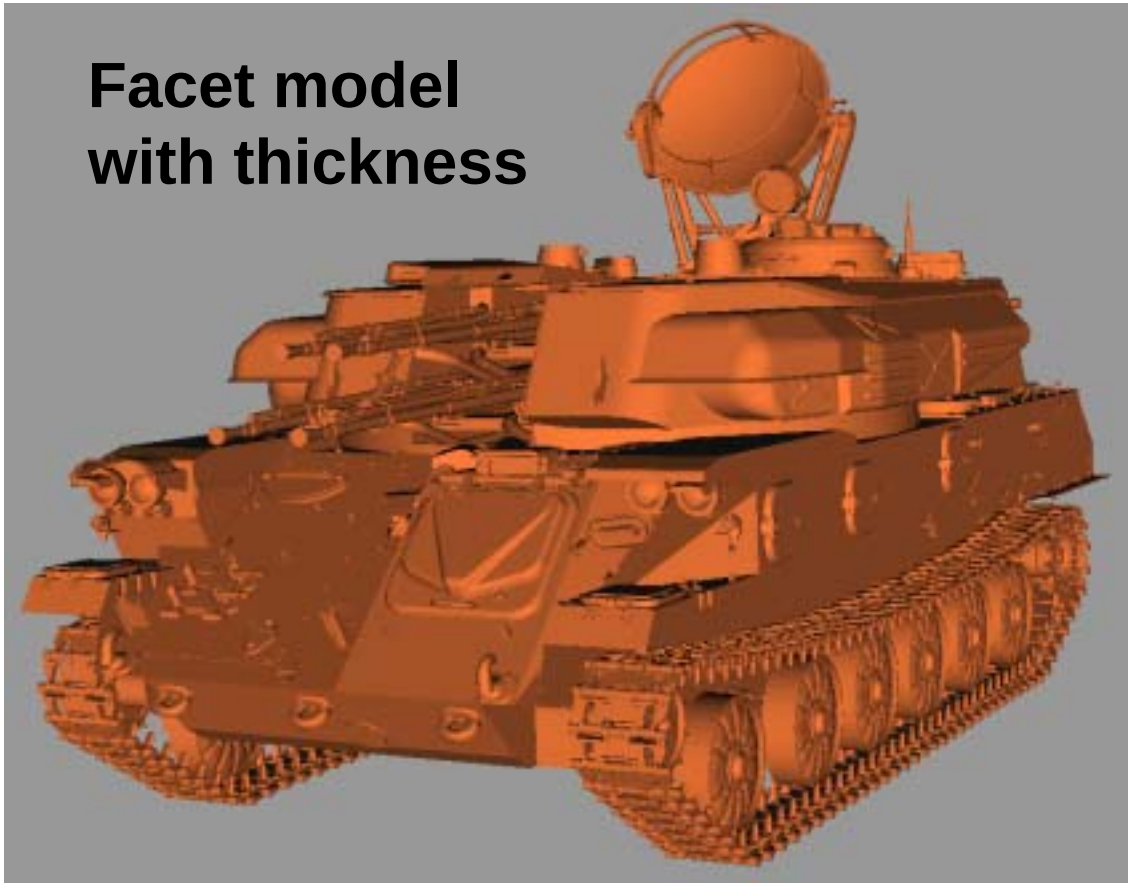
ZSU23-4 - (approximately 800k facets)

Original Surface Mesh



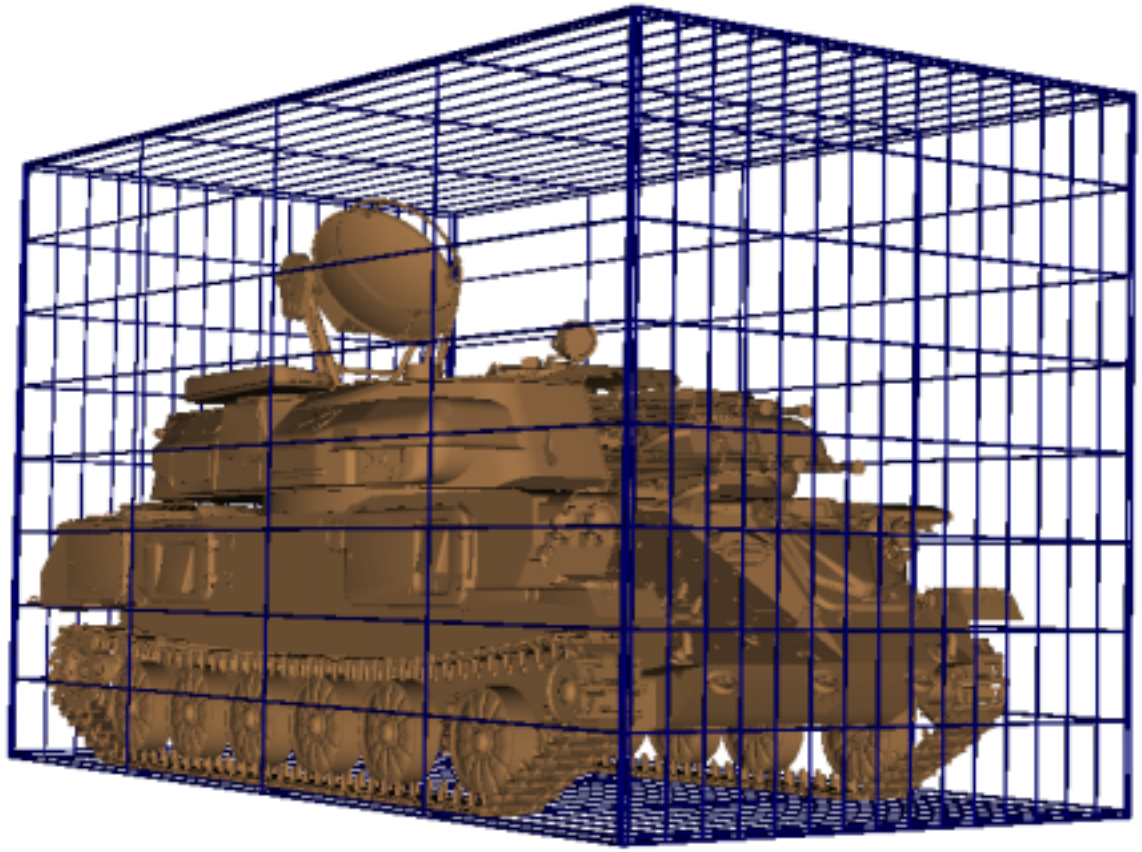
ZSU23-4 - Vehicle Detail

Mesh Pre-Processing



Facets given a thickness of 1.6cm (5 x 3.2mm)
Cell size 3.2mm for a grid resolution of 9-10 cells per wavelength

Partitioning / Decomposition

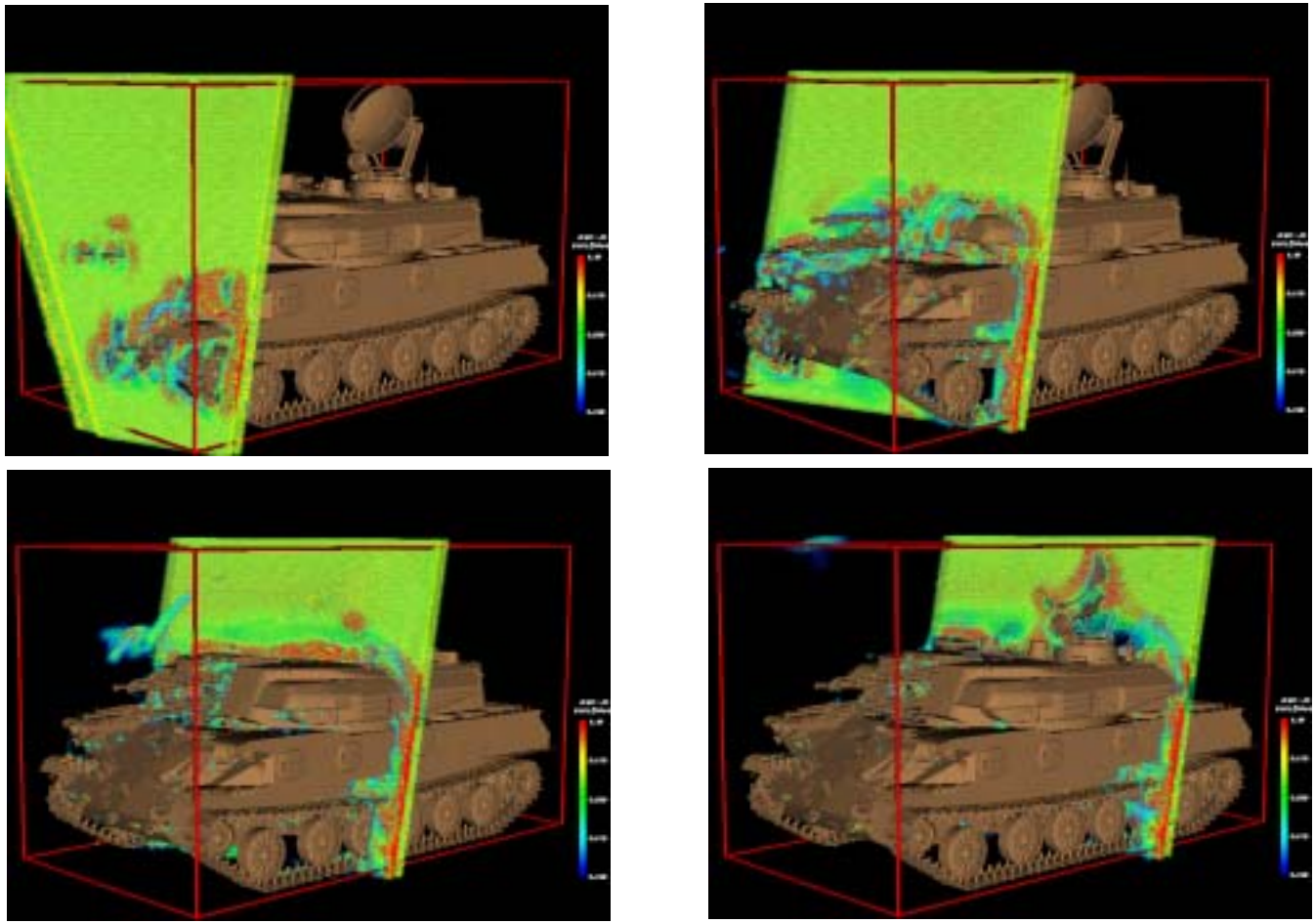


Partitions: 6 x 17 x 10

Cells: 1984 x 1043 x 1188 (2.46 billion)

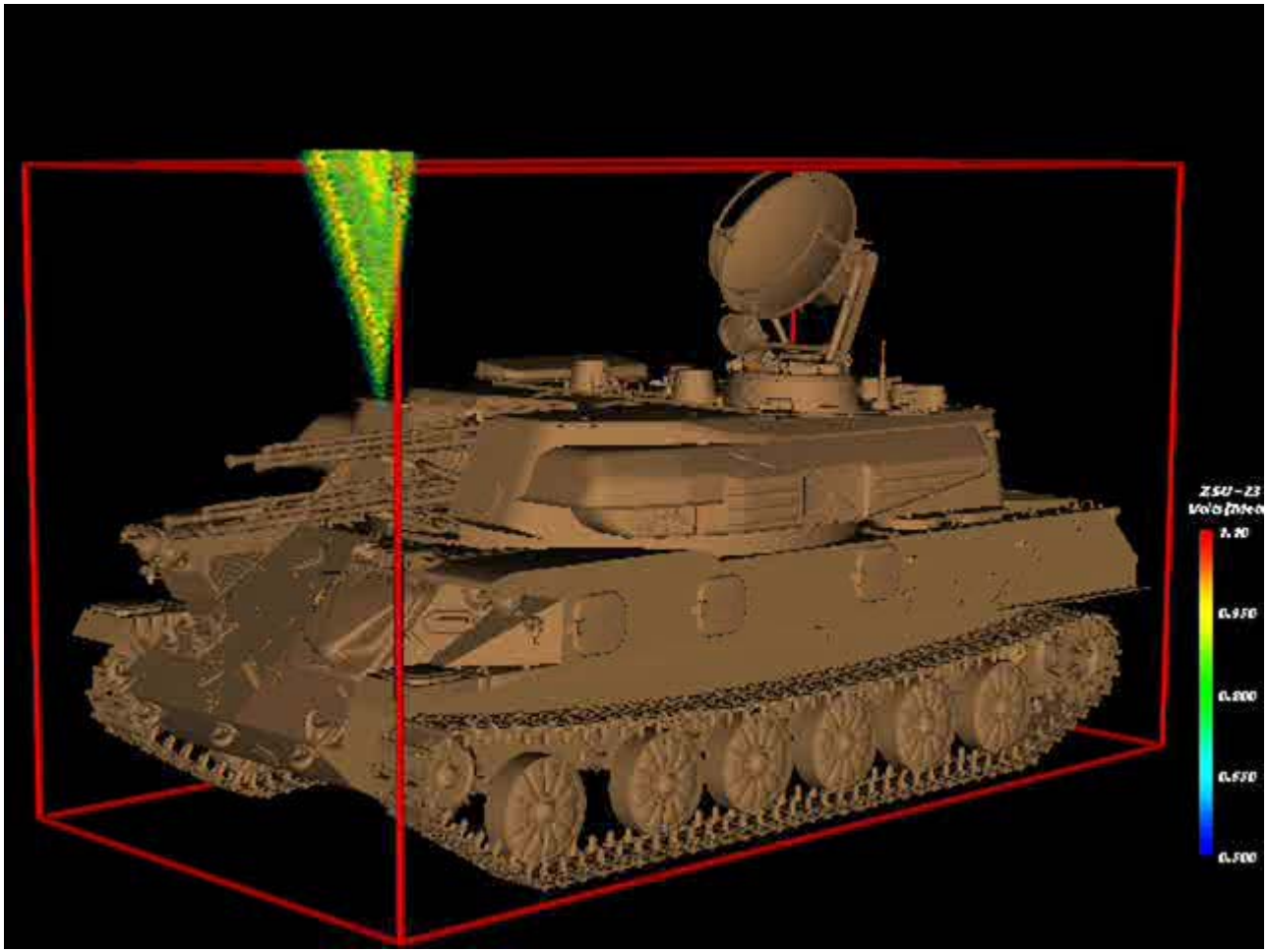
Run on 384 PE's on the ARL-MSRC IBM-SP3

Volumetric Results



(example showing magnitude of the E field for a 100MHz to 2GHz pulse)

Volumetric Results (Movie)



Example showing magnitude of the E field vector.

Concluding Remarks

Advantages

Fast mesh generation from FACET or CAD geometry utilizing parallel techniques

Limitations

Accuracy of original surface normals imported from facet files affect mesh generation.

Future Efforts

Incorporate true load balancing

Add multiple material capability

Additional Information

Interdisciplinary Computing Environment:

http://www.arl.hpc.mil/ice/

Supporting FY2002 DOD Challenge Project:

Signature Modeling for Future Combat Systems